Biochar Characteristics and Rates Affecting Corn Growth and Properties of Soils Contrasting in Texture and Mineralogy

Somchai Butnan [a] Patma Vityakon [a] Jonathan L. Deenik [b], Banyong Toomsan [a], Goro Uehara [b], and Michael J. Antal, Jr. [c]

[a] Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand.
[b] Department of Tropical Plant and Soil Sciences, University of Hawaii, Hawaii 96822, USA.
[c] Hawaii Natural Energy Institute, University of Hawaii, Hawaii 96822, USA

BACKGROUND

Studies on the use of biochar as soil amendments have been attracting a lot of scientific interest. Biochar not only enhances some soil fertility-related soil properties, but can also sequester soil carbon resulting in mitigation of global warming. Biochar characteristics vary with their production conditions, i.e., feedstock and pyrolysis techniques. In addition, their effectiveness as soil amendments may vary in different soils.

HYPOTHESES

Hyp1. Thai conventional kiln (TK) will produce biochar which has higher volatile matter (VM) content but lower ash and fixed C than Flash carbonization (FC) technique. Additionally, TK biochar will has lower C content but higher O, H, and N content than FC biochar.

Hyp2. Biochar will improve soil properties and plant growth more in the sandy (Khorat) soil than the clayey (Wahiawa) soil.

Hyp3. FC biochar will be more effective in improving soil properties and plant growth than the TK biochar.

Hyp4. Increasing biochar application rate will increase soil enhancement and plant growth.

OBJECTIVE

- To evaluate effects of biochar produced under contrasting pyrolysis techniques and their application rates on plant biomass and properties of soils contrasting in texture and mineralogy

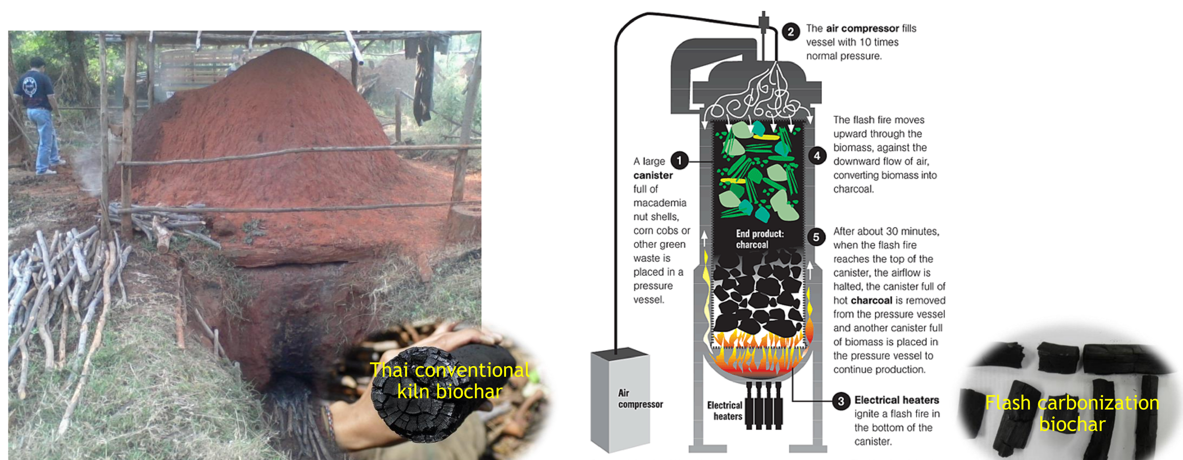
MATERIALS AND METHODS

BIOCHAR

Biochar was produced from the upper part of 5-year-old eucalyptus (*Eucalyptus camaldulensis*) wood under different pyrolysis techniques (Fig 1): **(a) Thai conventional kiln (TK), and (b) flash carbonization (FC) reactor**.

Pyrolysis Conditions of Biochar Production

- **TK biochar** was produced at 500°C in a clay kiln (Fig.1a).
- **FC biochar** was produced under a controlled flash fire at 1 MPa for 40 min with peak temperature reaching 800°C in the reaction canister (Fig.1b).



(a) (b)
Fig 1. Thai conventional kiln (a) and Flash carbonization reactor (b)

Biochar Characteristics

Biochar proximate analysis; i.e., volatile matter, ash, and fixed carbon contents, was analyzed using ASTM D 1762-84 standard method, while ultimate analysis; i.e., element contents, and ash composition were conducted by Hazen Research, Inc., Golden, Colorado (Table 1).

SOIL

Soils with contrasting texture and mineralogy were used(Table 2,3):

- **Khorat soil series** (loamy sandy, isohyperthermic Typic Oxyaquic Kandiustults) was collected from 0 – 15 cm-depth soil in Fruit Tree station ,Khon Kaen University, Thailand.
- **Wahiawa soil series** (very fine, kaolinitic, isohyperthermic, Rhodic, Haplustox) was collected from 0–15 cm-depth soil at the Poamoho Research Station, University of Hawaii, USA.

Table 1. Soil particle size distribution and texture of Khorat and Wahiawa soils

Soil	Soil particle size distribution % Sand	% Silt	% Clay	Soil Texture
Khorat soil	79.85	17.64	2.51	Loamy sand
Wahiawa soil	7.94	35.61	56.45	Silty Clay Loam

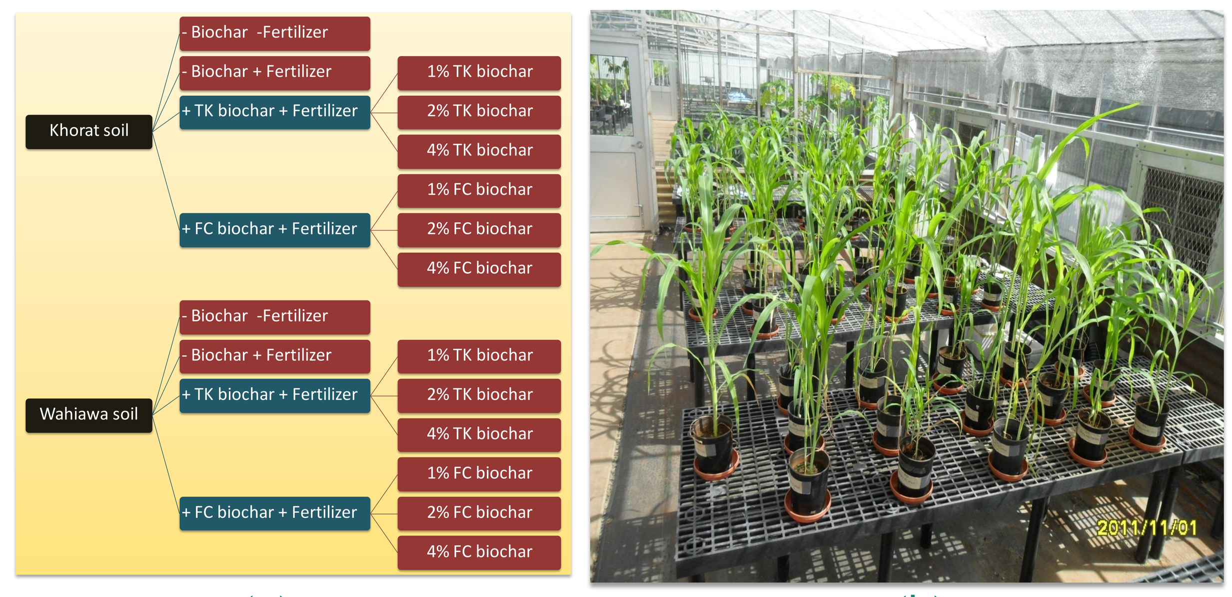
Table 2. Selected initial properties of Khorat and Wahiawa soils

Soil	BD	WHC	pH (Soil:H_2O = 1:5)	Bray2-P	Extractable cations K	Ca	Mg	Al	Mn
	(g cm^3)	(%)		(mg kg^{-1})	(cmol$_c$ kg^{-1})				
Khorat soil	1.43	20.5	5.52	5.73	0.04	0.28	0.09	4.25×10^{-2}	0.025
Wahiawa soil	0.91	63.4	6.04	6.26	0.80	1.27	0.66	8.47×10^{-5}	0.941

EXPERIMENTAL DESIGN

A greenhouse pot experiment was conducted in the University of Hawaii, USA testing two corn crop cycles. The experiment was arranged in 2 x 2 x 4 (soils, biochar types, and biochar rates, respectively) factorial arrangement in randomized complete block design with three replications.

MATERIALS AND METHODS (Continue)



(a) (b)
Fig 2. Treatments (a) and photograph (b) of the experiment

RESULTS AND DISCUSSION

EFFECT OF PRODUCTION TECHNIQUE ON BIOCHAR PROPERTIES

Table 3. Proximate and ultimate analysis results and ash composition of TK and FC biochars

Parameter	Content TK biochar	FC biochar
Proximate analysis (%) [a]		
Moisture	3.76	3.16
VM [d]	35.79	14.65
Ash	2.35	3.85
fC [e]	61.86	81.49
Ultimate analysis (%) [b]		
C	79.9	90.95
O	12.92	1.14
H	3.79	2.25
N	0.46	0.44
S	0.03	0.05
C:N ratio	174	207
C:O ratio	6	80
C:H ratio	21	40
Ash composition (g kg^{-1} biochar) [b]		
SiO_2 [c]	1.55	2.22
Al_2O_3	0.26	0.62
Fe_2O_3	0.72	3.28
CaO	7.57	14.58
MgO	0.71	0.97
K_2O	6.15	9.41
P_2O_5	1.14	1.97

[a] Dry basis -ASTM D 1762-84. [b] Analyzed by Hazen Research Inc., Golden, Colorado. [c] The ash was calcined at 600°C prior to analysis. [d] Volatile matter (VM). [e] Fixed carbon (fC). [f] Data not avaiable (N/A).

- TK biochar showed less thermal alteration with higher VM and lower ash and fixed carbon content than the FC biochar (Table 3).
- TK biochar had lower percentage of C but higher O, H, and N than FC biochar; further evidence that the FC biochar experienced a higher degree of carbonization
- Elements which were related to ash content were higher in FC than in TK. Therefore, Hyp1 was accepted.

EFFECT OF BIOCHAR CHARACTERISTICS ON SOIL PROPERTIES AND CORN GROWTH

Table 4. Analysis of variance of corn biomass of crop cycle 2

SOV	df	p-value
Block	2	
Soil	1	***
Biochar	1	**
Rate	3	***
Soil × Biochar	1	NS
Soil × Rate	3	NS
Biochar × Rate	3	*
Soil × Biochar ×Rate	3	NS
Error	30	
Total	47	
C.V. (%)	24	

[A] Source of variance (SOV). [b] Degree of freedom (df).
***Significantly different at $p < 0.001$; **Significantly different at $p < 0.01$; *Significantly different at $p < 0.05$; ns = not significant

- Biochar showed minimal effects on plant growth during crop cycle 1 (data not shown).
- Biochar significantly increased plant growth in the crop cycle 2 with significant soil, biochar, and rate effects (Table 4).

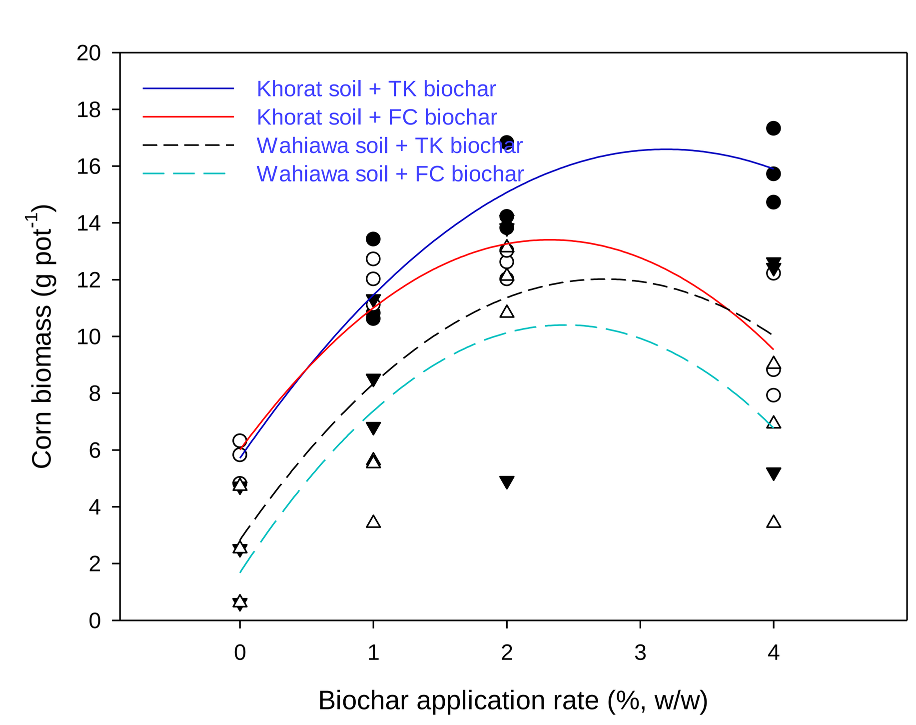


Fig 3. Relationship between corn biomass and biochar application rate of Khorat and Wahiawa soils amended with TK- and FC biochar

- Corn biomass in both Khorat and Wahiawa soils increased with biochar application rate (Fig 3), with higher growth response in Khorat soil than in Wahiawa soil (Hyp2 and 4 were accepted).
- However, contrary to expectation, biomass was higher with TK biochar than with FC biochar (Hyp3 was rejected).

RESULTS AND DISCUSSION (Continue)

- At the highest application rate of Wahiawa soil, corn biomass statistically decreased.
- The increase of corn biomass by biochar application rate was higher in TK biochar than in FC biochar. Corn growth of FC biochar decreased at the highest rate.

- Table 5 shows analysis of variance of soil properties of crop cycle 2.
- We considered which soil properties were major effects of corn growth by using Pearson correlation between corn biomass vs. soil properties and corn biomass vs. tissue nutrient uptake (Table 6).

Table 5. Analysis of variance of selected soil properties of crop cycle 2

SOV [a]	df	p-value BD	pH	P	K	Ca	Mg
Block	2						
Soil	1	***	***	***	***	***	***
Biochar	1	*	***	NS	**	***	NS
Rate	3	***	***	***	***	***	***
Soil × Biochar	1	NS	**	NS	*	NS	NS
Soil × Rate	3	*	*	*	**	NS	***
Biochar × Rate	3	NS	***	NS	NS	***	NS
Soil × Biochar × Rate	3	NS	NS	NS	NS	NS	NS
Error	30						
Total	47						
C.V. (%)		9.3	3.2	31.9	41.6	9.4	7.1

[a] Source of variance (SOV). [b] Degree of freedom (df).
***Significantly different at $p < 0.001$; **Significantly different at $p < 0.01$; *Significantly different at $p < 0.05$; ns = not significant

- Soil bulk density (BD) decreased with increasing application rate showing a negative correlation with corn growth (Table 6).
- FC biochar was more effective at decreasing soil BD than the TK biochar (Fig 4a).
- Macro-nutrients, i.e., N, P, K, Ca, and Mg, were important elements which were contributed by both TK and FC biochars (Fig 4b,c,d,e,f).

Table 6. Correlation matrix of corn biomass vs. soil properties and corn biomass vs. tissue nutrients

Corn biomass of	Soil properties pH	BD	P	Extractable cations K	Ca	Mg	Al	Mn	FDA	Tissue nutrient Concentration Mn	Uptake N	P	K	Ca	Mg
Khorat soil + TK biochar	0.125	-0.612	**-0.613**	**-0.776**	**0.647**	**-0.869**	-0.114	-	-0.217	-0.254	0.814	0.884	0.518	0.912	0.836
Khorat soil + FC biochar	0.094	-0.357	-0.492	-0.562	0.217	**-0.589**	-0.495	-	0.149	0.059	0.360	0.491	0.465	0.729	0.871
Wahiawa soil + TK biochar	0.564	-0.693	-0.191	**-0.637**	-0.148	**-0.756**	-	-0.175	-0.514	-0.591	0.835	0.816	0.789	0.917	0.877
Wahiawa soil + FC biochar	**0.618**	-0.711	-0.514	-0.465	0.164	**-0.667**	-	-0.434	-0.718	-0.476	0.845	0.790	0.649	0.898	0.829

In bold, significant values (except diagonal) at the level of significance alpha=0.050 (two-tailed test)

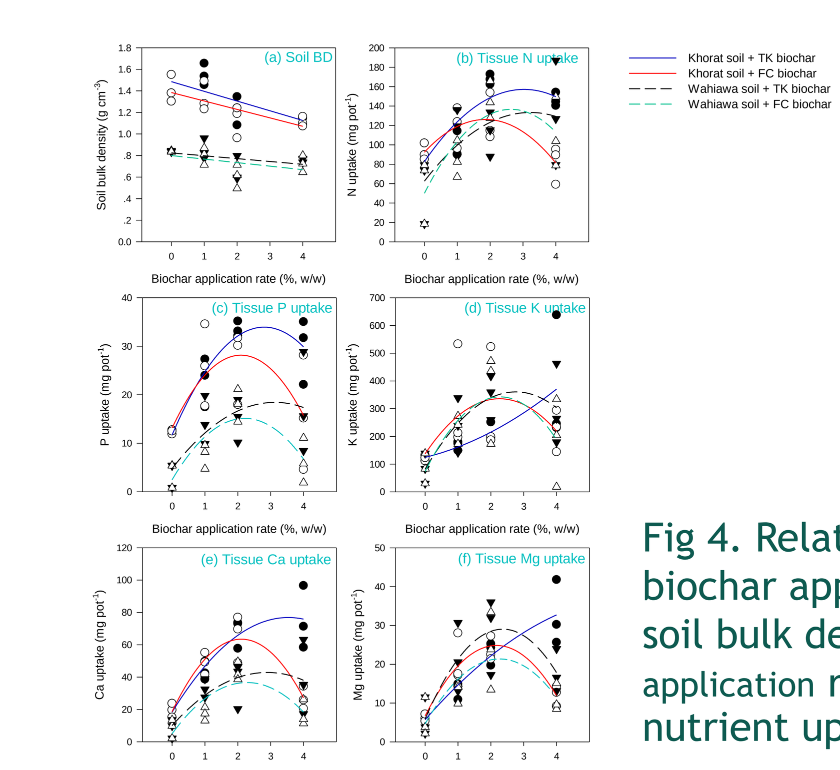


Fig 4. Relationship between biochar application rate vs. soil bulk density and biochar application rate vs. tissue nutrient uptake

Fig 5. Influence of biochars on corn growth in two soils with contrasting texture and mineralogy.

CONCLUSION

- Biochar properties varied significantly depending on pyrolysis conditions.
- Biochar effects were more pronounced in the sandy Khorat soil than in clay Wahiawa soil.
- Contrary to expectations, the TK biochar improved soil properties and plant growth more effectively than the FC biochar.
- Increasing biochar application rate increased soil enhancement and plant growth, except the highest rate.

ACKNOWLEDGEMENTS

This research was funded by the Royal Golden Jubilee Ph.D. Program under the Thailand Research Fund (TRF). Part of the research was funded by the Government of Thailand's Grant to Khon Kaen University (FY 2010 and 2011) and affiliate scholar of Memorandum of Understanding between the East-West Center (EWC), the University of Hawaii at Manoa (UHM), and the TRF. Additionally, this research is specially dedicated to our professor and friend, Dr.Goro Uehara.

SELECTED REFERENCE

Deenik, J.L.; Uehara, G.; Antal, M.J.; Campbell, S. *Soil Sci Soc of Am J*, **2010**, *74(4)*, 1259-1270.